Experimental Investigation of Nano-Polymercement Composite

Wail N. Al-Rifaie[*1], Waleed K. Ahmed[2], Omar M. Mahdi[3]

[1]Civil Engineering Department, Philadilphya University, Amman, Jordan

[2]ERU, College of Engineering, United Arab Emirates University, UAE

[3]Research Scholar, College of Engineering, University of Tikrit, Iraq

[*1]wnrifaie@yahoo.com; [2]w.ahmed@uaeu.ac.ae

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Abstract

The present research program was carried out to develop a new composite material to be considered for different applications. Hence, the present work concern with the development of a very thin structural element to be used for example, strengthening or rehabilitation of pipe lines for pressurized pipes rather than using polymeric composite materials, construct poles for lighting and wind turbine, manufacturing of underwater turbine blades and even impellers, water tanks and anti- bullet protective panels or even anti explosion sheets used in trucks. The development of nano structural element may then be called "nano-polymercement". The parameters considered during the investigation were micro sand, micro cement, nano silica, nano clay, naphthalene sulphonate and nano polymer mesh. In addition, the influence of heating on the compressive strength of nano cement mortar were discussed. It may be concluded that the ductility of nano-polymercement as developed in the present work which depends on the present of nano cement mortar and nano polymer mesh enables a large deflection to take place with no cracks.

Keywords

Nano Silica; Nano Clay; Nano Polymer Mesh

Introduction

Nanomaterials like nanosilica, carbon nanotubes and nanoalumina been used extensively over the last decade due to its exceptional contribution in enhancing the materials properties. However, nanomaterials are gaining widespread attention to be used in construction sector so as to exhibit enhanced performance of materials in terms of smart functions and sustainable features. Literatures demonstrate the use of nanomaterial in cementitious system is mainly due to the fact that concrete remains the most complex material and its hydration mechanism is still not completely understood (Singh et al., 2013). Jo et al. (2007) studied experimentally the properties of cement mortars with nano-SiO_2. The results show that the compressive strengths of mortars with nano-SiO_2 particles were all higher than those of mortars containing silica fume at 7 and 28 days. It was demonstrated that the nano-particles are more valuable in enhancing strength than silica fume. The effect of elevated temperatures on chemical composition, microstructure and mechanical properties of high strength mortars with nano alumina was investigated (Farzadnia et al., 2013). Residual compressive strength, relative elastic modulus and gas permeability coefficient of samples were also obtained. Nano alumina enhanced compressive strength of samples up to 16% and improved residual compressive strength. An increase in the relative elastic modulus, higher energy absorption and lower permeability were also observed when 1% nano alumina was added. Many studies have targeted the application of clay in cement composites and declared some enhancement on the properties of concrete. However there is little knowledge on nanoclays and their effect on the mechanical properties and durability of cement composites. Halloysite nanoclay is one of the subcategories of nanoclay that has been undeservedly ignored in the production of cement composites. Chemically, the outer surface of the halloysite nanotubes has properties similar to SiO_2 while the inner cylinder core is related to Al_2O_3 which together may improve the cement matrix. Farzadnia et al. (2013), studied the mechanical properties, flowability, thermal behavior and durability of mortars containing halloysite nanoclay. It was demonstrated that compressive strength and gas

permeability of samples with nanoclay were improved. SEM, XRD, DSC tests were carried out to investigate the microstructure and chemical composition change in samples with halloysite nanoclay. Effect of nano clay particles on mechanical, thermal and physical behaviours of waste-glass cement mortars was investigated (Aly et al., 2011). The microstructure, ASR, fracture energy, compressive and flexural properties of cement mortars containing WGP as a cement replacement with and without NC are investigated and compared with plain matrix. In addition, the hydration of cement compounds was followed by differential thermal analysis (DTA), thermogravimetric analysis (TGA), and also X-ray diffraction (XRD). The results showed that incorporation of glass powder has a positive effect on the mechanical properties of cement mortars after 28 days of hydration. Also, the results revealed that the mechanical properties of the cement mortars with a hybrid combination of glass powder and NC were all higher than those of plain mortar and with glass powder after 28 days of hydration. The compressive strengths and the microstructure photographs of cement mortars containing nanosilica with various sizes compared with cement mortar with silica fume (Haruehansapong et al. 2014) . Tested results indicated that NS significantly improved compressive strength of cement mortar and the strength improvement was also dependent on the NS particle size. These results indicate that the particle size of nanosilica affected only the compressive strength of cement mortar, but it had no effect on the optimum replacement content. The results of microstructure photographs are also supported the compressive strength and optimum replacement content results. Mendoza et al. (2014) studied the effect of the reagglomeration process of Multi-Walled Carbon Nanotubes (MWCNT) dispersions on the activity of silica nanoparticles at early ages when they are combined in cement matrixes. MWCNT/water/superplasticizer dispersions were produced via sonication and combined with nanosilica particles in the mixing water of the cement samples. X-ray diffraction, isothermal calorimetry, thermogravimetric and mechanical strength analysis were carried out to identify variations in the hydration reaction induced by the combination of these nanoparticles. It was found that the early activity of the nanosilica (NS) is accelerated, decelerated or completely inhibited by the reagglomeration process of the MWCNT dispersions, depending on MWCNT and $Ca(OH)_2$ amounts in the media. The methods and theories of in situ growth of CNTs/CNFs on cement/mineral admixture, including chemical vapor deposition method and microwave irradiating conductive polymers method were summarized (Sun et al., 2013). Properties of the cement-based composites made from the CNTs/CNFs-grown cement/mineral admixture were presented. Li et al. (2004) experimentally studied the mechanical properties of nano-Fe_2O_3 and nano-SiO_2 cement mortars. The experimental results showed that the compressive and flexural strengths measured at the 7th day and 28th day of the cement mortars mixed with the nano-particles were higher than that of a plain cement mortar. The SEM study of the microstructures between the cement mortar mixed with the nano-particles and the plain cement mortar showed that the nano-Fe_2O_3 and nano-SiO_2 filled up the pores and reduced $CaOH_2$ compound among the hydrates. These mechanisms explained the supreme mechanical performance of the cement mortars with nano-particles. In this article, the 56-day pore structures of the cement mortars produced by the addition of silica fume and nano-SiO_2 (NS), nano-Al_2O_3 (NA) and nano-Fe_2O_3 (NF) powders in singular, binary or ternary combinations at different proportions of the binder content were investigated through MIP and BET analyses (Oltulu and Sahin, 2014). The compressive strengths and capillary water absorptions of produced mortars were also determined in order to investigate the effects of changes in pore structure on these properties. As a result, it was found that pore structures of the mortars determined by MIP and BET were influenced by the choice of singular, binary or ternary uses as well as the content of nano-powder(s) added into the mortar. The flexural strength of a very thin ferrocement element by using NSCSC mortar as a replacement to the normal cement mortar usually used in ferrocement elements was examined. The measured results demonstrate the increase in flexural strength of a very thin ferrocement using NSCSC mortar (Al-Rifaie et al., 2012). Al-Rifaie et al. (2013), examined the compressive and flexural strength of nanocement mortar by using micro cement, micro sand, nanosilica and nanoclay in developing a nanocement mortar which can lead to improvements in ferrocement construction. The measured results demonstrate the increase in compressive and flexural strength of mortars at early stages of hardening. In addition, the influence of heating on compressive strength of cement mortar, whereas ferrocement eco-housing system was able to produce very energy efficient dwellings (Al-Rifaie et al., 2014). Finite

element method was used to investigate the impact of inclusion (Ahmed et al., 2007), cracked nanocomposite (Ahmed et al., 2012), debonding (Ahmed, 2013), pre-crack (Ahmed et al., 2013), mismatch (Ahmed and Shakir, 2013), nanoinclusion (Ahmed and Al-Rifaie, 2013), interfacial debonding (Ahmed, 2013b), interfacial deffects (Ahmed, 2013c) and fractured particulate composite (Ahmed and Teng, 2014), on the characteristics and failure of the nanocomposite.

Experiment

Materials

Cement: Micro Portland cement sulphate resistance, conforming ASTM C150 type II, particle size (45-0.7)μm.

Sand: Micro sand (300-75)μm, conforming ASTM C33.

Silica: Nano silica (500-100)μm, it contents particles less than 40μm.

Clay: Developed nano clay (200-3)μm by burning the clay up to 700°C.

Naphthalene sulphonate used as super-plasticizers.

Nano polymer mesh: The nano polymer mesh used in the present work has a polymer wire having thickness and aperture of 0.17 mm and 2.36 mm respectively.

Figure 1 Shows the details of nano polymer mesh used in the present investigation. The measured yield strength Fy, elastic modulus of Ew, and ultimate tensile strength Fu, were obtained using direct tensile tests. The average values of modulus of elasticity (Ew), upper yield stress (Fy), and ultimate tensile stress (Fult) of polymer mesh were 210 GPa, 406 MPa, and 607.6 MPa respectively.

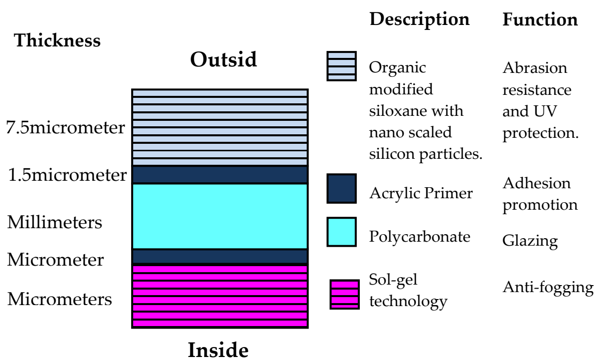

FIG. 1 CROSS-SECTION IN THE NANO POLYMER MESH USED IN THE PRESENT INVESTIGATION

By using electron microscope it was found that there are dormer hairs with nearly 1 mm in length and 5nm in diameter at the surface of nano polymer mesh and this may increase the bond between nano polymer mesh and nano cement mortar.

The following expression is used to determine the volume fraction V_f of the nano polymer layer:

$$V_f = \frac{N * bb * tb}{h} \left(\frac{1}{Dl} + \frac{1}{Dt}\right) \quad (1)$$

Where,

N=Number of nano polymer mesh layers.

bb=Width of polymer wire in mm.

tb=Thickness of polymer wire in mm.

h=thickness of prism in mm.

Dl=Distance between the center of each adjacent two wires of the nano polymer in the direction parallel to the prism space in mm.

Dt=Distance between the center of each adjacent two wires of the nano polymer in the direction perpendicular to the prism space in mm.

It was clarified in Al-Rifaie et al. (2013) that the highest compressive strength and modulus of rupture can be achieved by considering the developed nano cement mortar having micro sand/ micro cement ratio of 1.5, 18% nano clay, 10% nano silica and 1.4% naphthalene sulphonate, with w: c ratio = 0.34 after 28 curing days. Hence, the developed nano cement mortar as mentioned above is adopted through the present work. More details of the developed nano cement mortar may be found in reference (Al-Rifaie et al., 2012).

For measuring the flexural strength F_r and modulus of elasticity E_{np} of nano-polymercement a total of 714 beam specimens 500x50xd mm, varying the thickness d, were cast using the developed cement mortar and reinforced with a number of nano polymer mesh layers uniformly distributed throughout the cross-sections. It may be noted that 378 of these beam specimens were subjected to freezing and heating (-20 to 800°C). All beam specimens were subjected to 28 curing days prior to three point bending tests, volume fraction V_f is assumed to be same for all beam specimens.

Results and Discussion

Table 1 gives the outcomes of transverse deflections due to heating (100 to 800°C) of the casting nano polymercement beam specimens varying the thickness and number of polymer mesh layers.

TABLE 1 MEASURED DEFLECTIONS OF THE BEAM SPECIMENS DUE TO HEATING

Temp. °C	Measured deflections, mm						
	(1) d = 6 n = 8	(2) d = 5 n = 6	(3) d = 4 n = 6	(4) d = 3.5 n = 4	(5) d = 3 n = 4	(6) d = 2.5 n = 4	(7) d = 2 n = 4
100	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0
300	0	0	0	0	0	1	0
400	1	0.8	1	1	2	4	4
500	2.8	2.5	2.6	2.6	3	6	6
600	4.5	5.1	5.1	6.3	6	8	8
700	6	6.9	7	7.8	10	9	11
800	7.5	8	8.5	8.9	14	15	16

Note: Each of the measured values given in Table 1 is the average of the measured values of six beam specimens.

The following are empirical expressions for determining the transverse deflections due to heating:

(1) = 0.0155T – 4.8838
(2) = 0.0174T – 5.6867
(3) = 0.018T – 5.8667
(4) = 0.0196T – 6.3467
(5) = 0.00004T2 – 0.0155T + 1.3286
(6) = 0.00002T2 – 0.0054T + 1.7143
(7) = 0.029T – 8.6857

As stated earlier, 378 nano polymercement beam specimens 500x50xd were subjected to both freezing and heating, 36 specimens subjected to freezing, -10 and -20°C, and 342 specimens subjected to heating, 20 and 100 to 800°C with 100°C interval, then these specimens were subjected to three point bending test for determining the flexural strength (modulus of rupture) and the temperature in which the nano polymer mesh layers broken as given in the following table. It was noted that the beam specimens subjected to freezing are failed by broking the nono polymer mesh at -10 and -20°C at flexural strength of 30.33 N/mm^2.

d mm	n	Temperature in which the nano polymer mesh layers were broken
6	8	800 °C @ δ_e =15 mm, F_r =16.7 N/mm^2
5	6	800 °C @ δ_e =12 mm, F_r =12.5 N/mm^2
4	6	800 °C @ δ_e =12 mm, F_r =12.5 N/mm^2
3.5	4	800 °C @ δ_e =13 mm, F_r =12.5 N/mm^2
3	4	600 °C @ δ_e =35 mm, F_r =18.2 N/mm^2
2.5	2	600 °C @ δ_e =35 mm, F_r =18.2 N/mm^2
2	2	600 °C @ δ_e =35 mm, F_r =18.2 N/mm^2

Note: d = thickness of beam specimen, n = number of nano polymer mesh layers
δ_e= cracking deflection, F_r =modulus of rupture.

Three point bending tests were performed on the beam specimens given in Table 1. It is depicted from Table 2 that the outcomes of transverse deflections at mid-span due to point loads applied at mid-span. In addition, the modulus of elasticity determined using the following formula:

$$E_p = \frac{PL^3}{48\Delta I} \qquad (2)$$

Where,

P=Applied load.

L=Clear span.

$\Delta=\delta_t$ obtained from empirical expression of Table 2.

TABLE 2A MEASURED DEFLECTIONS AT MID-SPAN OF THE BEAM SPECIMENS 500*50*6 MM DUE TO HEATING AND POINT LOADS APPLIED AT MID-SPAN

Temp. °C	Bending stresses at first cracking loads σ, MPa using beam theory	Total deflection δ_t in mm	Empirical expression for determining the total deflection δ_t, mm and the value of modulus of elasticity E_p
17	12.5	25	δ_t = 22.083+0.077σ - 0.016T E_p = 5.923 GPa
100	16.667	18	
200	16.667	20	
300	16.667	22	
400	20.833	17	
500	20.833	16	
600	16.667	15	
700	12.5	10	
800	12.5	10	

TABLE 2B MEASURED DEFLECTIONS AT MID-SPAN OF THE BEAM SPECIMENS 500*50*5 MM DUE TO HEATING AND POINT LOADS APPLIED AT MID-SPAN

Temp. °C	Bending stresses at first cracking loads σ, MPa	Final total deflection δ_t in mm	Empirical expression for determining the total deflection δ_t, mm and the value of modulus of elasticity E_p
20	12.5	25	δ_t = 22.662 +0.146 σ - 0.018T E_p = 12.8 GPa
100	16.667	18	
200	16.667	20	
300	16.667	22	
400	20.833	17	
500	20.833	16	
600	16.667	15	
700	12.5	10	
800	12.5	10	

TABLE 2C THE MEASURED DEFLECTIONS AT MID-SPAN OF THE BEAM SPECIMENS 500*50*4 MM DUE TO HEATING AND POINT LOADS APPLIED AT MID-SPAN

Temp. °C	Bending stresses at first cracking loads σ, MPa	Total deflection δ_t in mm	Empirical expression for determining the total deflection δ_t, mm and the value of modulus of elasticity E_p
20	11.22	25	δ_t = 21.85+0.205 σ - 0.0196T E_p= 20 GPa
100	15.433	23	
200	16.667	22	
300	16.667	22	
400	20.833	19	
500	20.833	18	
600	16.667	14	
700	12.5	12	
800	12.5	10	

TABLE 2D MEASURED DEFLECTIONS AT MID-SPAN OF THE BEAM SPECIMENS 500*50*3.5 MM DUE TO HEATING AND POINT LOADS APPLIED AT MID-SPAN

Temp. °C	Bending stresses at first cracking loads σ, MPa	Final total deflection δ_t in mm	Empirical expression for determining the total deflection δ_t, mm and the value of modulus of elasticity E_p
20	10.777	23	δ_t = 22.083+0.077σ - 0.016T E_p = 21.325 GPa
100	15.433	20	
200	16.667	17	
300	16.667	17	
400	20.833	15	
500	20.833	15	
600	16.667	14	
700	12.5	13	
800	12.5	12	

TABLE 2E MEASURED DEFLECTIONS AT MID-SPAN OF THE BEAM SPECIMENS 500*50*3 MM DUE TO HEATING AND POINT LOADS APPLIED AT MID-SPAN

Temp. °C	Bending stresses at first cracking loads σ, MPa	Final total deflection δ_t in mm	Empirical expression for determining the total deflection δ_t, mm and the value of modulus of elasticity E_p
-20	30.33	49	δ_t = 22.083+0.077σ - 0.016T E_p = 25.55 GPa
-10	30.33	50	
20	26.66	53	
100	26.66	55	
200	26.66	52	
300	26.66	50	
400	20.11	49	
500	18.21	35	
600	15.13	24	
700	14.33	19	

TABLE 2F MEASURED DEFLECTIONS AT MID-SPAN OF THE BEAM SPECIMENS 500*50*2.5 MM DUE TO HEATING AND POINT LOADS APPLIED AT MID-SPAN

Temp. °C	Bending stresses at first cracking loads σ, MPa	Final total deflection δ_t in mm	Empirical expression for determining the total deflection δ_t, mm and the value of modulus of elasticity E_p
-20	30.33	49	δ_t = 22.083+0.077σ - 0.016T E_p = 28.74 GPa
-10	30.33	50	
20	26.66	53	
100	26.66	55	
200	26.66	52	
300	26.66	50	
400	20.11	49	
500	18.21	35	
600	15.13	24	
700	14.33	19	
800	10.45	20	

TABLE 2G MEASURED DEFLECTIONS AT MID-SPAN OF THE BEAM SPECIMENS 500*50*2 MM DUE TO HEATING AND POINT LOADS APPLIED AT MID-SPAN

Temp. °C	Bending stresses at first cracking loads σ, MPa	Final total deflection δ_t in mm	Empirical expression for determining the total deflection δ_t, mm and the value of modulus of elasticity E_p
-20	30.33	49	δ_t = 22.083+0.077σ - 0.016T E_p = 32 GPa
-10	30.33	50	
20	26.66	53	
100	26.66	55	
200	26.66	52	
300	26.66	50	
400	20.11	49	
500	18.21	35	
600	15.13	24	
700	14.33	19	
800	10.45	20	

Note: Each of the measured values given in Table 1 is the average of the measured values of six beam specimens.

Expression for determining the modulus of elasticity of the composite nano polymer mesh and nano cement mortar is formed as follows:

$$Ep = -6.4441t + 44.841 \qquad (3)$$

Where,

t:is the thickness of the beam specimen in mm.

A comparison is made between the values of transverse deflection obtained from Table 2, δt, and the values obtained using expression (3) as shown in Figure 2.

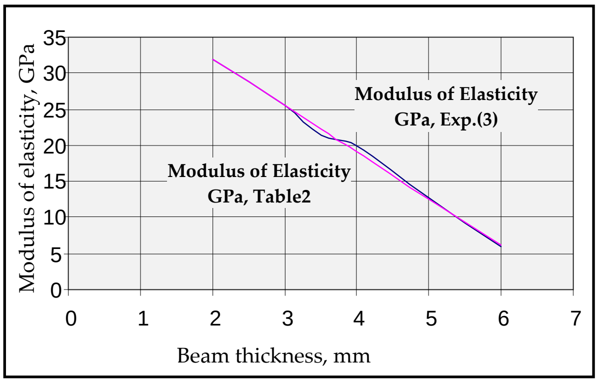

FIG. 2 RELATIONSHIP BETWEEN MODULUS OF ELASTICITY AND BEAM THICKNESS.

Conclusions

It may be concluded that the ductility of nano polymer mesh-nano cement mortar composite as developed in the present work which depends on the present of nano cement mortar and nano polymer mesh enables a large deflection to take place with no cracks.

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Wail N. Al Rifaie is the former President of University of Technology, Baghdad where holds a chair in the Building and Construction Engineering Department. He received his Ph.D in Structural Engineering from University College, Cardiff, U.K. in 1975. Professor. Wail also received the Telford Premium Prize from the Institution of Civil Engineers in 1976 on the strength of his doctoral work. He is former Chair of the Scientific Research Commission within the Ministry of Higher Education and Scientific Research, Iraq and is held in the utmost regard within the Iraqi academic community. He has been awarded numerous national honors including the Outstanding Professor Award (1996), the Science Merit Medal (2001) and the Science Decoration in the same year. Professor Wail has supervised 58 M.Sc. Theses and 15 Ph.D. Theses and published over 100 scientific papers, the majority of which concern ferrocement elements, including membrane roof structures, box beams, load bearing walls and columns, hydraulic containment structures and thin shells such as roof domes. He also is the author of 7 respected monographs in the field of structural analysis.

Waleed K. Ahmed In 1992, Dr. Ahmed got his B.Sc. in Mechanical Engineering from the College of Engineering, University of Baghdad-Iraq. Served for 6 years industrial sector in the manufacturing and the quality control. In 2000 got M.Sc. in Applied Mechanics from the Mechanics and Equipment Department at the University of Technology, Baghdad-Iraq in the failure analysis of pipes using FEA. Appointed as a lecturer at the Materials Engineering Department in the College of Engineering at the University of Mustanseryia, Baghdad-Iraq in 2001. At the mid of 2006 finished his PhD in the field of strengthening of steel pipes using composite materials, where the research was done in collaboration with Nottingham University as MOU. Moved to work in United Arab Emirates University occupying many positions starting from the end of 2006. Moreover, published more than 40 journal and conference papers. Main interest in renewable energy, nanomaterial, failure analysis, FEA, NDT, solid mechanics, wind turbine as well as fracture mechanics. At the present time, Dr. Ahmed is a faculty in the ERU at the College of Engineering-UAEU, Al Ain city, Unite Arab Emirates University.